Comp 4300 Project

Enhancing Network Efficiency : Integration of MAC protocol using dynamic bandwidth allocation

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***Abstract*—The purpose of this report is to explore integration of various MAC protocol algorithms, including Frequency Devision Multiple Access (FDMA), Time Division Multiple Access (TDMA) and Random Access Scheme. In this project. The main objective is to determe the benefits of combining various MAC protocols and analyze the throughput of these hybrid approaches. The modifications includes combining FDMA and random access and combining FDMA with TDMA with and without dynamic time slot adjustment, Through running network simulation using python simulation framework simpy, it is concluded that these hybrid approach does improve the throughput from 10% to 50%.**

***Keywords— MAC protocols, FDMA, TDMA, random access, selective repeat, network algorithm.***

# Introduction

*A. Motivation*

Selective repeat and MAC protocols play a critical role in transport later and data link layer in the OSI model. In this project a few modifications to these protocols are made and simulated using Python event-based simulation framework Simpy, aiming to improve the overall throughout of transmissions.

Selective repeat mechanism aims to provide an efficient way to ensure data integrity in the transport layer by selectively resending corrupted or lost packets. It uses selective acknowledgement and retransmission to maintain data integrity even in poor network conditions.

MAC protocols on the other hand, operates in data link layer. It’s primary purpose is to define how devices share the same medium effectively. FDMA allows multiple devices to transmit at the same time by dividing the channel into different frequencies. However, the fixed allocation can result in unused bandwidth and lead to lower efficiency. TDMA cooperate multiple devices by allocating time slots to different devices in a cyclic manner. But TDMA also suffers from wasted resource due to inactive devices holding the bandwidth during their allocated time slots. Although Random access scheme does not suffer from the problem, an increase in number of devices can result in higher number of collisions and inefficiency. To address these problems, a mechanism that allocate bandwidth dynamically to different devices based on the each device's bandwidth requirement is needed to effectively allocate the shared channel’s bandwidth and improve overall throughput.

*B. Real-Life Applications*

When considering the benefits of using dynamic approach to allocate bandwidth in the MAC protocol, it is important to consider ways to determine the bandwidth requirement of different devices. Some approaches includes:

* Using statistical approach to determine devices bandwidth usage, dynamically allocate bandwidth resources to devices based on device's historical usage in different time period of the day.
* Utilizing RNN machine learning model to process each device's short term traffic data and make prediction of their bandwidth usage.
* Using AI model to analyze device's usage pattern and allocate bandwidth resources.
* Supporting device's bandwidth allocation based on their priority.

Next this report will discuss MAC protocols simulation set up and Analysis of the results.

# II. MAC PROTOCOLS SIMULATION

**To Run:** All MAC Protocol simulations uses python simpy simulation Framework. To run each simulation, ensure simpy is installed (**pip3 install simpy**). Then run each python script with: **python3 script\_name.python.**

**Simulation Conditions and Assumptions:** All simulation simulates 9 nodes sending data with various load from 1 to 9. Where node 1 has the lowest data load and node 9 has the highest data load. It is also assumed that the time taking 1 node to send 1 packet under full bandwidth is 2 time unit. The total bandwidth of the chanel does not change. All simulation is ran for 1000 time units and their performance metrics are shown in a graph.

*A. FDMA: Uniform vs. Stratified Bandwidth allocation (FDM.py)*

Figure 1 shows the number of frames sent by the 9 nodes of various load (10 to 90) but with same bandwidth. Figure 2 shows the frames sent by the 9 nodes that are allocated with a bandwidth speed proportional to their data load. That is, node with higher data load is assigned to a band with higher bandwidth and vice versa. It is clear that stratified bandwidth allocation based on node's data load has a higher overall througput of 0.458 packets/timeunit.

A graph with colorful lines

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Figure . FDMA with Uniform bandwidth allocation

A graph of different colored lines

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Figure . FDMA with Stratified bandwidth allocation.

*B. FDMA+ TDMA: Reduce idling time slot in TDMA by intergrating TDMA into different bands.(TDM.py, FDM\_TDM.py)*

Figure 3 shows the packets sent by using TDM. All 9 nodes share the same bandwidth in a single channel, which results in an overall throuput of 0.193 packets/ time unit and 193 packets sent. Then the 9 nodes are dividied into 3 groups: low data load (10,20,30), medium data load(40,50,60), high data load(70,80,90) and put into 3 bands with low, medium and high bandwidth speed. Figure 4.1 shows this approach increases the throughput by around 39%, from 0.193 packets/time unit to 0.268 packets/time unit. Figire 4.1, 4.2 and 4.3 shows the packets sent by each band, with increasing throughput from band 1 to band 3. This is expected since band 1 has lowest bandwidth and nodes with lower data load and vice versa.

A graph of a graph

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Figure . Regular TDMA

.A graph of a number of data

Description automatically generated with medium confidence

Figure .1. FDMA+TDMA. All 3 bands.

A graph showing a line of data

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Figure 4.2 FDMA+TDMA. Band 1 (low bandwidth) Figure 4.3 FDMA+TDMA. Band 2 (medium bandwidth)

A graph of a number of data

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Figure 4.4 FDMA+TDMA. Band 3 (high bandwidth)

*C. FDMA+ TDMA: Reduce idling time slot by dynamicly allocating time slot to nodes based on their data load within each band from B (FDM\_TDM\_DynamicTimeSlot.py)*

This simulation is an enhancement of B. After grouping nodes and putting them inside a band with corresponding bandwith based on the node's data load, furthur optimization within the band can be done. In simulation B, although the overall throughput improves after combining FDMA and TDMA, Figure 4.2, 4.3 and 4.4 shows that the nodes within each band still transmitt at similar rate as the lines represending nodes in each bands cluster together. Thus in this simulation each node is assigned with dynamic number of time slots. For instace, in band 1, node 1 gets 1 time slot to trasmitt, while node 2 and node 3 with higher data load get 2 and 3 time slots. In band 2, node 1 gets 1 time slot to transmit, while noe 2 and node 3 get 2 time slots each.

The result of this simulation can be found in Figure 4: the overall transmited packets is 466 and the throuput is 0.268 packets/time unit, which is 74% higher than that in the FDMA+TDMA simulation without the dynamic slot allocation, and 140% higher than that in the TDMA simulation. Compraing Figures 4.2, 4.3 and 4.4 to Figures 5.2, 5.3 and 5.4, it is clear that the nodes within a band start to differentiate in number of packets transmitted. The nodes with lower data load (node 1 in each band ) does not loss too much throughput, while the nodes with higher data load (node 2 and 3 in each bands) starts to pick up speed when utilizing dynamic time slot allocation within each band.

A graph of a number of packets

Description automatically generated with medium confidence

Figure . FDM+TDM with dynamic time slow allocation. All 3 bands

A graph of a graph

Description automatically generated with medium confidenceA graph of a number of different colored lines

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Figure 5.2 FDM+TDM with dynamic time slow allocation. Band 1 Figure 5.3 FDM+TDM with dynamic time slow allocation. Band 2

A graph of a number of data

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Figure 5.4 FDM+TDM with dynamic time slow allocation. Band 3

*D. FDMA+Random Access: Reducing Collision Rate in MAC Random Access by integrating random access scheme within seperate band (randomAccess.py, FDM\_randomAccess.py)*

Figure 6.1 shows the simulation result of running random access for node 1 to 9 within a single band. The collision rate is 45.82% Figure 6.2 shows the collision vs frames sent for each node. Figure 7.1 shows the simulation reuslt of integrating random access into FDMA. Nodes are grouped together and assigned to a band based on their data load. Band 1 contains nodes with lower data load, and has the lowest bandwidth. Band 3 contains nodes with high data load, and has the highest bandwidth.

Comparing this hybrid approach to the original random access protocol, the collision rate drops by almost half, from 45.82% to 22.74% . Figure 7.2 shows the collisions vs frames sent for this hybrid approach as well. Comparing to figure 6.2 where most nodes have a higher collision numbers than the packets sent, the hybrid approach effectively reduce collisions in all node. However, node 3 in band 2 and node 2,3 in band 3 seems to be hogging all the bandwidth due to inaccurate simulation in simpy framework. This is to be improved in the future.

Overall combining FDMA with Random Access isolates the nodes in each band, effetively reducing the collisions and improve the overall throughput by about 16.5% from 0.38 to 0.46 packets/time unit.

*.* A graph with numbers and a chart

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Figure .1 Random Access Transmissions

A graph with red and blue bars

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Figure 6.2. Random Access Collisions

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Figure .1.FDMA+Random Access Transmission

A graph with blue and red squares

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Figure 7.2. FDMA+Random Access Collisions

*E. MAC protocols conclusion:*

By identifying device's data load and dynamicly allocate bandwidths to them, the MAC protocols can achieve a higher efficiency. The overall transmission throughput can be improved by the following approach shown in the simulations:

* Stratified allocaion of bandwidth based on node's load rate in FDMA.
* Reduce idling time slot in TDMA by intergrating TDMA into different bands.
* Reduce idling time slot by dynamicly allocating time slot to nodes based on their data load within each band.
* Reducing Collision Rate in MAC Random Access by integrating random access scheme within seperate band.